ENGINEERING CASE LIBRARY

ECL 169A

SPONTANEOUS FRACTURE (A)

"I'm sending a couple of fellows around to your office. They're having some problem with failures on hard hats. I told them you might be able to help them." That was the department chairman. I was not as sure as he was that I could help them. I had plenty of design experience both in industry and now in a university but my experience with hard hats and with design of plastics was minimal.

Names in this case have been disguised

 Prepared by Professor G. Kardos with support by the National Science Foundation.

SPONTANEOUS FRACTURE (A)

When Mr. J. A. Lami and Mr. Bowan turned up in my office they carried with them a number of the offending hard hats. (Figure 1) They introduced themselves respectively as the General Manager and the Chief Engineer of Owl Equipment Limited of Helen, Ontario.

Owl Equipment Ltd. is a supplier of safety equipment and other appliances to municipalities and to contractors. They do little manufacturing of their own, but act as agents for equipment manufactured by others. In some cases they import the elements and do the final assembly themselves. The hard hats in this case were imported from Germany. The hat and the head harness are received separately and assembled by Owl Equipment Ltd. (Figures 2, 3, and 4)

Owl Equipment had submitted and received approval for the headwear from the Canadian Standards Association. The headwear had successfully passed all tests and had received CSA listing.

Owl Equipment had recently received a rash of warranty claims on helmets. The harness holders in the hat were failing. From the examination of the returned hats Mr. Lami and Mr. Bowan concluded that the majority of failures were in the right side holder, (Figures 4, 5, and 6) although failures were not exclusively confined to this holder. Failures had occurred in other holders but not to the extent as in the right side holder.

Because the nylon head harness is an interference fit in the holders, (Figures 3,7, and 8) Mr. Lami and Mr. Bowan suspected that the right hand holder on the corresponding insert was oversize, resulting in overloading. They asked for my help in measuring the various parts to determine if their suspicions as to size were correct.

Measurements on the inserts were easily made and the right side insert was found to be .003 in. to .008 in. thicker than the other inserts. Measurement of the holder could not be readily made because it was relatively inaccessible and because the compliability of the plastic made it difficult to make reproducible readings.

Further discussion with Mr. Lami and Mr. Bowan established that they were not really looking for dimensional variation

but for an explanation for the failures. In the discussion it came out that there was a difference of opinion between Owl Equipment and the German supplier of the headwear. The supplier claimed that these failures were only occurring in headwear at Owl Equipment and, therefore, it must be because of incorrect assembly or misuse. Owl Equipment were of the opinion that there was something wrong with the design or manufacture of the headwear. They felt that the breakage was, therefore, the responsibility of the supplier.

The problem now changed from one of measurement to determination of cause of the holder failure. Questioning Mr. Lami on the occurrence of the failures he stated that the exact time of failures could not be established and there was no pattern to the service failure. The most noticeable fact was that a large number of failures took place while the headwear was stored.

The returns on the headwear had been coming in through the months of January, February, and March which lead to suspicion of low temperature as a cause of failure.

Examination of the headwear and the broken lug showed that the holder had extremely sharp inner corners (Figures 7 and 8) leading to the supposition that the resultant high stress concentrations may be the cause.

The fracture surfaces showed typical brittle fracture (Figures 5 and 6). An attempt to reproduce this type of failure by pulling on the ears of the holder was unsuccessful. The ears of the holder could be bent through a large angle without fracture. When failure occurred a stringy torn surface was produced. The surface produced by overloading had no resemblance to the brittle fracture due to service failure. The nature of the failure surface would lead one to suspect fatigue in a metal but this was plastic and there was no cyclic loading.

Mr. Lami could not say exactly what the headwear material was nor whether the failure had a higher frequency with color. He promised to send me further information after examining the records. Meanwhile, I was to carry out some tests to determine if low temperature or low temperature cycling could cause the failures. For this purpose they left a number of failed and sound hats with me.

Mr. Lami indicated that there was some urgency in determining the cause of failure. A senior executive from the German supplier was coming to Canada and would be visiting them in about 6 weeks. Lami felt that it was important to have something

for him to resolve the disagreement on responsibility for the failures.

They subsequently wrote giving what data they could on the hat material and on the frequency of failures with color. (Exhibit A-1)

To investigate the effects of low temperatures, one sample of the hats was cold cycled from room temperature to 25°F., both with the harness inserted during cycling and without harness inserted. Where harness was not inserted the harness was pressed into the holder at the low temperature cycle. No failure occurred.

An attempt was made to cause failure in the holder by overloading at 25°F. using a pair of pliers. The overload caused failure in the same manner and with the same appearance as at room temperature, a long stringy tear.

The low temperature cycling was carried out on another sample cycling from room temperature to 0°F. without causing failure. This time overloading of the holder ear at 0° produced a brittle fracture. Considerably larger deflection took place before failure occurred than could be accounted for by normal loading.

Parallel to the testing above I made a literature search into the nature of polyethylene and other plastics and into the design criteria for plastics. The most useful source I found was "Engineering Design for Plastics" by Baer.

The low temperature experiments and the literature search were carried out in approximately 1-1/2 weeks. Actual time devoted to carrying out the investigation including the literature search and preparation of the report was nearly 50 hours. When it came time to bill Owl Equipment I realized that some of this time could not legitimately be charged since it was devoted to educating myself in plastic design. I arbitrarily decided to bill them for two days at standard consulting rates.

Armed with the experimental results, the results of my examination of the failed parts, and Baer's book, I was prepared to write a report to Owl Equipment on the probable reasons for the failures and recommendations to prevent recurrence.

Figure 1

HARD HAT

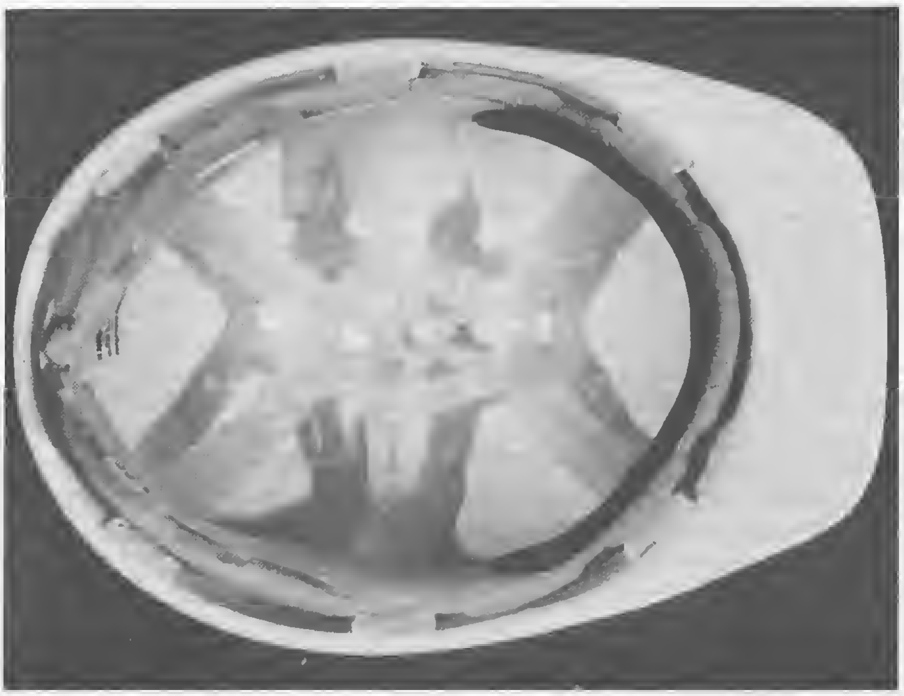

Figure 2

HARD HAT WITH HEAD HARNESS INSTALLED

Figure 3

HARNESS INSERT

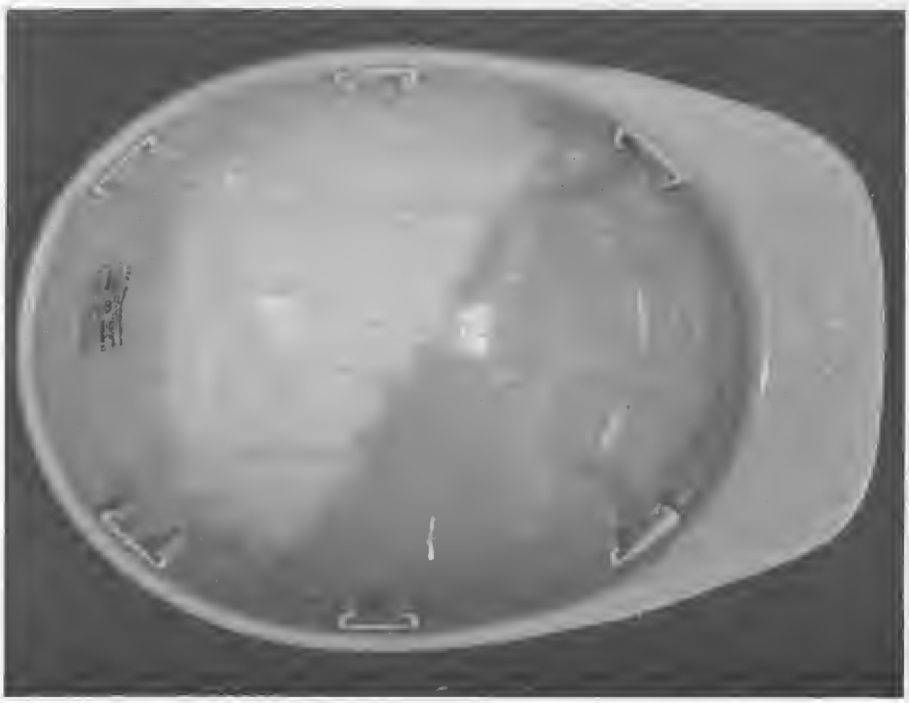

Figure 4

HARD HAT WITH HARNESS REMOVED

Figure 5

BROKEN HARNESS HOLDER

Figure 6

BROKEN HARNESS HOLDER

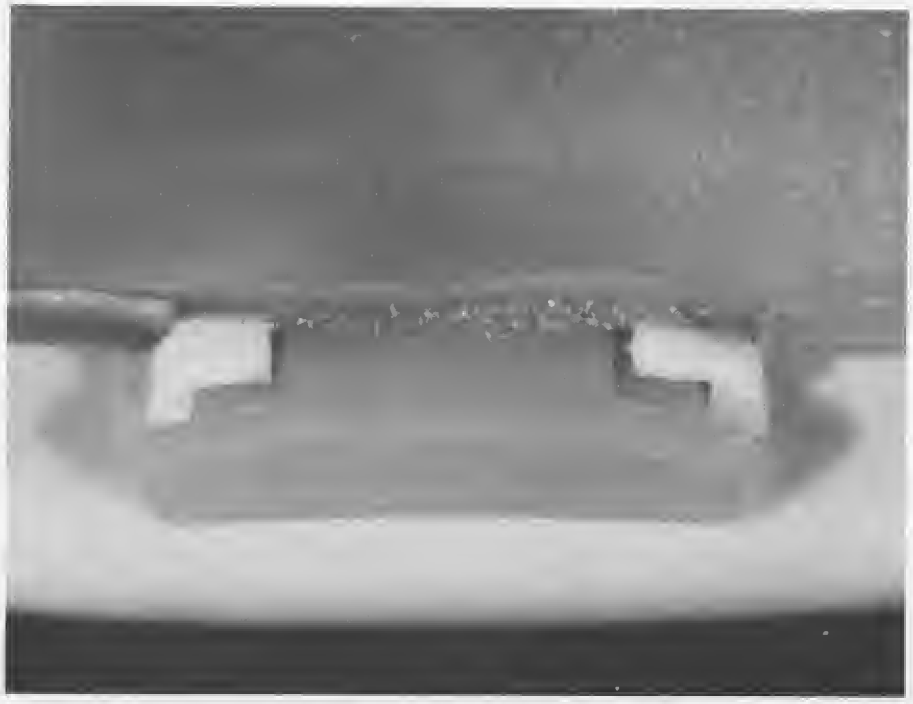

Figure 7

HARNESS HOLDER WITH HARNESS INSERTED

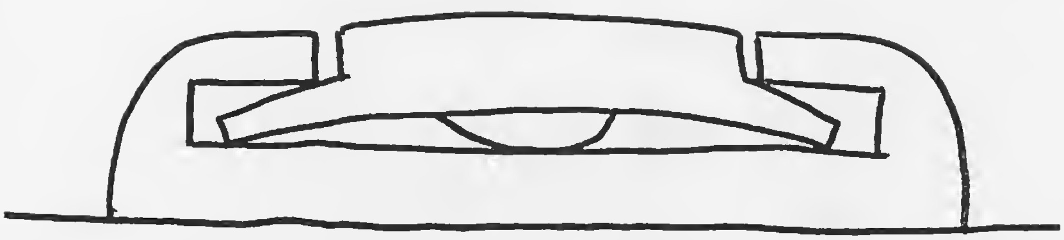

Figure 8

SKETCH OF HARNESS HOLDER SHOWING INTERFERENCE FIT

June 6, 1969

Dr. Geza Kardos
Engineering Faculty
McMaster University
Hamilton, Ontario

Dear Dr. Kardos:

Thank you for the time you spent with Mr. Bowan and me discussing the problem we are having with the hard hat.

Enclosed are the CSA standards for headwear tests. The hats have been tested by CSA and approved as Class B.

The hat is a polyethylene mixture. However, the exact mix is known only by the manufacturer and is not available to us.

The holder which appears to be breaking the most is the one in which the insert has the date of manufacture. That is the right side holder when the hat is on. The next highest failure is the front left.

The hat is breaking under various conditions, however, the most noticeable is breakage while on shelf. We have not heard of any breakage under impact.

Based on breakage vs. sales for the months of Jan., Feb., and March the following are results by colour:

Orange	$\frac{416}{5140}$	or 8.1% failures.
Green	$\frac{300}{4824}$	or 6.2% failures.
Red	$\frac{420}{7200}$	or 5.8% failures.
Yellow	476	or 5.6% failures.

EXHIBIT A-1

Facsimile of letter - Owl Equipment Limited to Dr. Kardos

White	$\frac{404}{8124}$	or 5.0% failures.
Blue	$\frac{12}{3800}$	or 0.3% failures.
Totals	$\frac{2028}{37598}$	or 5.4% failures.

It would appear that the only significant factor is that of the blue caps not failing.

However, this sample is not too good because the failures are only those which we have had returned. It is possible that some hats have failed and have not been reported because of their being carried in inventory and not inspected.

Trusting this information will help in your search to find the answer to this problem, I am

Yours truly,

Owl Equipment Limited

A. Lami
General Manager

EXHIBIT A-1
Facsimile of letter - Owl Equipment Limited
to Dr. Kardos

ENGINEERING CASE LIBRARY

ECL 169B

SPONTANEOUS FRACTURE (B)

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REPORT

FAILURE OF HEADWEAR HOLDERS

Prepared for

Owl Equipment Ltd.
Helen, Ontario

Respectfully submitted
on this 20th day of June, 1969

G. Kardos, Ph.D., P. Eng.
Associate Professor
Mechanical Engineering
McMaster University

20 June 1969

Mr. J. A. Lami
Owl Equipment Ltd.
P. O. Box 1039
Fort Erie, Ontario

Dear Mr. Lami:

I take pleasure in submitting my report on the Causes of Failures in the Hard Hats.

I believe that the prime cause of failure was static fatigue due to an unsatisfactory design resulting in high stress concentrations. Other environmental factors may have contributed to the failures, but if the stress concentrations had not been present they would not have caused failure by themselves.

I thank you for the opportunity to assist you and trust that the report meets with your satisfaction. Please call me if any questions arise or if any clarification is needed.

Yours truly,

G. Kardos, P. Eng.

GK/sc

INTRODUCTION

The following is a report on results of examination and tests on headwear submitted to the author by Owl Equipment Ltd. The conclusions and recommendations are based upon information received in Owl Equipment letter of 6th June 1969, conversations with Mr. Bowan and Mr. Lami of Owl Equipment and examinations of whole and failed headgear.

NATURE OF THE FAILURE

The side holders of the headwear were failing after some time in the field; the largest number of failures were in the right side holders.

The failures, in all samples examined, originated at the inner corner (Point A, Figure 1). The fracture surfaces had a brittle appearance without any suggestion of ductility.

Field reports indicate that failures have occurred in approximately 5% of sales over a three month period. There was no significant variation with color. Failure occurred in various areas and was not confined to a single region or industry.

Of particular significance is the fact that the failures took place even on the shelf.

Loading

In service, the holders are loaded by insertion of a suspension attachment into the holder, (Figure 2). The geometry of the suspension attachment causes an interference fit which produces a bending moment and shear on the ears of the holder (M in Figure 1). This interference fit subjects the holders to a constant load throughout its life. During insertion, the button on the attachment is often sheared giving considerable variation in actual load. During the life of the element cold flow can be expected to reduce the loads due to the interference fit.

Physical Examination

Dimensional checks on the various samples supplied indicated that suspension attachments on the left and right side were consistently .005 to .008 in. thicker than others on the suspension; this could result in a higher stress in these holders due to a greater interference.

Test

Because of the brittle nature of the fracture an attempt was made to reproduce this type of failure by excessive loading.

(a) Room temperature - bending the lugs far beyond the working position did not produce the characteristic failure. Yielding was apparent at inner corner A but fracture did not occur.

(b) Freezing - the helmets were put through at temperature cycle of 25°F to room temperature several times. No fracture occurred. Overloading the lugs did not produce brittle fracture.

(c) Zero degrees Fahrenheit - helmets were cycled through 0°F to room temperature. No fracture occurred. Overloading at 0°F produced brittle fracture.

Stress Cracking

A survey of the literature indicates that plastics and particularly polyethelene are subject to stress-cracking. Stress cracking is discussed extensively in "Engineering Design for Plastics" by Baer.

Stress cracking is characterized by surface-initiated fracture under polyaxial stress at a stress level below which failure would not normally be expected to occur. Various forms of stress cracking have been identified mainly by the environmental conditions initiating the cracking, environmental stress cracking, solvent cracking, thermal stress cracking, and static fatigue.

Regardless of the mode of stress cracking, they all occur in the presence of polyaxial stress. Because failures in

the helmets occurred at different locations and different environmental conditions most environmental initiators must be discarded.

Static fatigue is probably the source of the failure. Static fatigue requires maintenance of a continuous load over a finite time. A typical example of static fatigue is given by Baer of a high density polyethelene moulding - a moulded flashlight cap failed in service under ordinary temperatures under a combination of its internal stresses and those supplied by the battery contact spring. In appearance, it is a typical brittle fracture.

Design

Because failure is taking place under load it is instructive to examine the stress characteristics of the load bearing member; specifically the lug of the side holder. This element is expected to carry both bending moment and shear.

The geometry of the element is such that the section is thinnest at A as well as having a sharp re-entrant corner. Therefore, not only would the stress be maximum at the thin section but the sharp corner would give rise to stress concentrations of considerably greater than three (Figure 3). In addition, these stresses would be polyaxial.

The only reason that this element does not fail under static loading is the large compliability of the plastic.

Conclusions

The lugs failed in static fatigue due to the high stresses induced in the re-entrant corners.

Factors that may have contributed to the failure are environmental conditions and low temperature cycling. Insufficient data is available to isolate the specific environment. In any case, environmental factors would not be the prime cause of failure.

Recommendations

The principle contributor to failure can easily be corrected by eliminating the stress concentration. This

could be accomplished by introducing a radius at Point A, preferably, such that the section thickness stays constant or increases (Figure 4).

This change can be readily introduced by simply modifying the moulding die inserts.

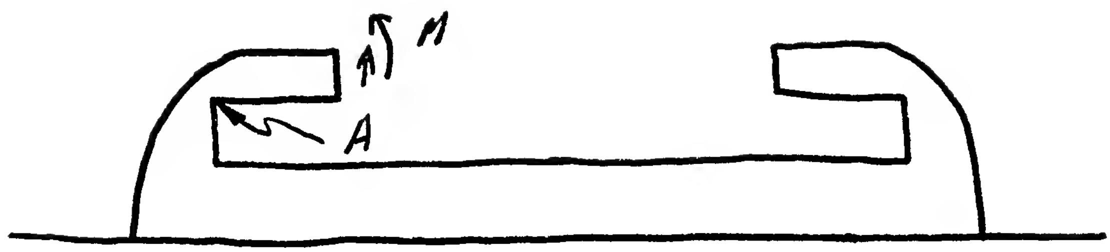

Figure 1

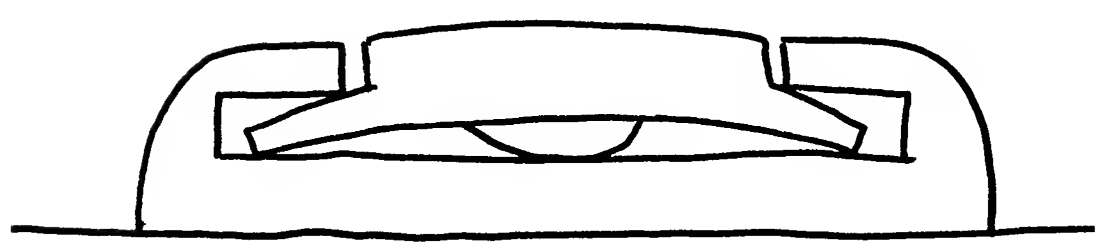

Figure 2

DESIGNING WITH PLASTICS

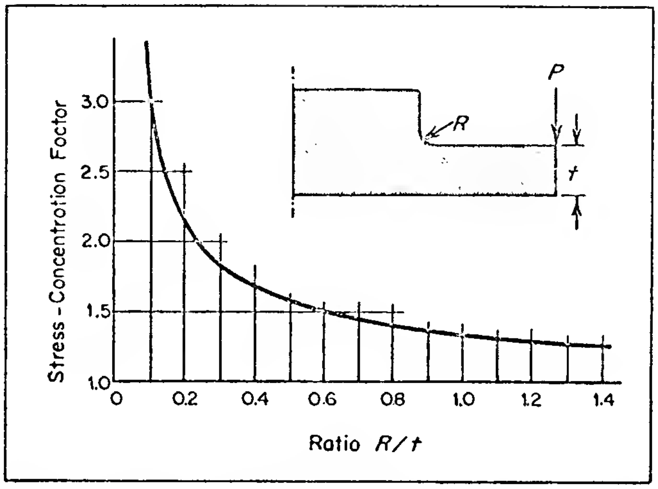

Fig. 11—Effect of fillet radius on stress-concentration factor. P = applied load; R = fillet radius; t = section thickness. *Data, courtesy SPI.*

Figure 3

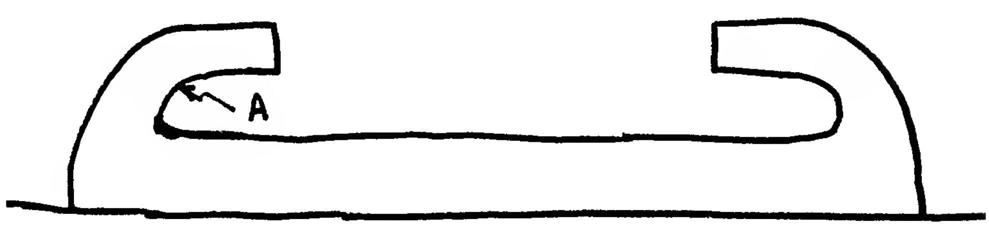

Figure 4

INSTRUCTOR'S NOTE

Spontaneous Fracture

This case can be used on several levels with students. First, it can be used to introduce students to requirements for designing with plastics. Most undergraduate instruction by necessity concentrates on design with metallic materials. Discussion of this case will bring out shortcomings of this narrow view.

Discussion of Part A of the case can be focused on the following questions:

1. The service loading on harness holder.
2. Type of stress distribution in failed section of holder? One dimensional? Two dimensional? Three dimensional?
3. Failure modes to be expected in plastics
4. Definition of fatigue
5. Low temperature effects on plastics
6. Method of manufacturing hard hats
7. Stress concentrations

The student can be directed to "Engineering Design for Plastics" by Baer for a solution to the failure problem.

Part B contains the report to the customer assessing the cause of failure. This part of the case can be used as a medium for exploring with the student the requirements of a technical report. The report in the case can be examined critically for its good points and its shortcomings. Starter questions for discussion of Part B:

1. What is the purpose of the report?
2. How well does it achieve its objectives?
3. If this report was for internal use in a large company should it have the same form?
4. What use would Owl Equipment make of this report?

The conclusion in the report can also be evaluated in terms of the discussion on the first part of the case.